Men and Milestones in Optics. V: Michael Faraday

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It is fitting that we should at this time take note of the life and accomplishments of Michael Faraday—possibly the greatest of all experimentalists in the physical sciences—because 1967 is the centenary of his death.

After Oersted's 1819 discovery that an electrical current produced a magnetic field, the converse effect was sought by many before Faraday found out how to produce it. This success stimulated him to search for other interrelations among the "forces of matter" at intervals thereafter. As he put it in the opening paragraph of *Experimental Researches in Electricity, Nineteenth Series, No. 26...Action of magnets on light...*[1],

> I have long held an opinion, almost amounting to conviction, in common I believe with many other lovers of natural knowledge, that the various forms under which the forces of matter are made manifest have one common origin; or, in other words, are so directly related and mutually dependent, that they are convertible, as it were, one into another, and possess equivalents of power in their action.

This paper was written on 29 October 1845 and presented before the Royal Society of London on 20 November 1845.

While a detailed treatment of Faraday's investigations and discoveries cannot be given here, we turn now to a brief survey of some of his most notable work, taking it roughly in chronological order.

Faraday's first notable discovery (one which led to an unjustified and unfair charge of plagiarism[2]) came in September 1821 when he achieved continuous rotation of a current-carrying conductor around a magnet, and *vice versa*, putting to use the newly discovered transverse type of force and opening the way to electric motors.[3]

His next important work combined physics and chemistry and dealt with the liquefaction of gases. Partly by accident, in 1823 he liquefied chlorine and then went on to other gases.[4] This work was not without its hazards, as indicated by Faraday's comment: "I have been interrupted twice in the course of experiments by explosions, both in the course of eight days—one burnt my eyes, the other cut them; but I fortunately escaped with slight injury only in both cases, and am now nearly well". After one explosion thirteen pieces of glass were removed from his eyes!

About this same time he did considerable work on the improvement of steel (with J. Stodart)[5], and one of his greatest chemical discoveries, benzene, came in 1825. He devoted much effort to the making of improved optical glass[6], and the piece that he used in 1845 dates from this time.

Between 1821 and 1825 Faraday had also made some casual and unsuccessful experiments in the hope of

Fig. 1. Michael Faraday. From the portrait facing page 72 of *Men of Science*, by J. G. Crowther (W. W. Norton and Company, 1936, New York).

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inducing electrical currents. He took up this problem again in August 1831, and on 29 August he had the first intimation of success. On the fourth experimental day, 1 October, induced currents were definitely produced and identified as such. This investigation actually took in all only ten days spread over August to November, the last being 4 November. Thus, in less than three months he had made a thorough investigation of the phenomenon, and had laid the basis for the modern electrical generator. His results were presented at the Royal Institution on 24 November 1831 and 12 January 1832.[7]

In passing we may note that Faraday was then forty years old and had been at the Royal Institution for eighteen years.

The public reaction to his discovery ranged from a poem celebrating it, composed by the physiologist Herbert Mayo[8], in Blackwood's Magazine to the sentiments expressed by an Oxford professor who, when he saw a spark produced by induction, remarked with foreboding that this put a new destructive device into the hands of the burners of hayricks.

The world of science is fortunate in that detailed accounts of this and subsequent experimental work are to be found in the remarkable diary that he kept from September 1820 onward. On 2 February 1839 he began to number the paragraphs consecutively: the last paragraph, on 6 March 1860, was numbered 18,041. This detailed running account of a genius at work was transcribed and published in seven large volumes in 1932; it is illustrated with reproductions of Faraday's sketches and interesting photographs.

As the years passed his reports appeared in "series" published at intervals in the Philosophical Transactions of the Royal Society.[9] They were also collected into three volumes entitled *Experimental Researches in Electricity*, which appeared in 1839, 1844, and 1855.[10] A collection of fifty-five of his most important studies of a nonelectrical nature, *Experimental Researches in Chemistry and Physics*, was published separately in 1859: this volume also includes his interesting "Observations on Mental Education".

As is well known, much of Faraday's work was paralleled by that of Joseph Henry, who anticipated Faraday by being first to announce the discovery of self induction.[11] The remarkable parallelism of the work of these two great men brings to mind the fact that Faraday worked in an Institution founded by an American, while Henry worked in an Institution founded by an Englishman.

Faraday's brilliant work in electrochemistry, correlating electrical charges and chemical affinity, established one of the most important links between chemistry and physics. His first paper on electrochemical decomposition appeared in 1833[12], and his great generalizations appeared in 1834.[13] To facilitate discussing his new investigations, he introduced the terms electrolysis, electrolyte, electrode, anode, cathode, ion, anion, cation, and ionization.[14] Almost as a by-product, he devised the voltameter as an instrument for measuring charge—and, indirectly, current—and is considered by some as having been the first to conceive of a fundamental unit of charge. His work in electrolysis has been memorialized by the designation of 96,500 C as one faraday. At that time there was considerable lack of certainty that voltaic, magneto-, thermo-, and "animal" electricities were identical with "common" (frictional) electricity. Faraday thus put an end to much confusion by proving in 1833 that there was only one kind of electricity, regardless of its origin.[15]

Faraday's famous studies of dielectrics (his word) and of electrostatic charges began about 1837. Though anticipated around 1773 in some respects by Cavendish (who did not publish), Faraday independently originated the idea of "specific inductive capacity" (to use his term), obtained values for it, and carefully investigated the polarization of dielectrics and the behavior of capacitors.[16] His famous "ice pail" experiment was worked out in 1843.[17]

The problem of action at a distance puzzled Faraday, as it had Newton, and in order to deal with it he adopted the concept of "lines of force" (used earlier by T. J. Seebeck), which was fundamentally equivalent to the modern concept of field.[18]

About 1840 his unremitting efforts brought him to the brink of physical and mental collapse, and he took an enforced vacation. By about 1844 he had, fortunately, remarkably and almost unexpectedly made a nearly complete physical recovery and regained much of his mental energy. On 13 September 1845 he turned to investigating possible magnetic effects on a polarized beam of light. His detailed notes (see Fig. 2) for that day tell us that no effects were observed with the first four materials he tried, and then comes the record of his discovery (using a piece of glass that he had made himself about 17 years earlier):[19]

> A piece of heavy glass which was 2 inches by 1.8 inches, and 0.5 of an inch thick, being a silico borate of lead, and polished on the two shortest edges, was experimented with. It gave no effects when the *same magnetic poles* or the *contrary* poles were on opposite sides (as respects the course of the polarized ray)—nor when the same poles were on the same side, either with the constant or intermitting current—BUT, when contrary magnetic poles were on the same side, there *was an effect produced on the polarized ray*, and thus magnetic force and light were proved to have relation to each other. This fact will most likely prove exceedingly fertile and of great value in the investigation of both conditions of natural force.

During the month that followed, Faraday explored the new phenomenon thoroughly using all of the materials available in his laboratory (including 150 aqueous solutions) and arrived at a clear understanding of the basic governing laws, which he announced in his paper.

Among his studies was a fruitless effort to observe the magnetic effect which Kerr found thirty-two years later.

The discovery of the Faraday effect came, as we have said, shortly after his return to the laboratory and was announced on 20 November. That same November he

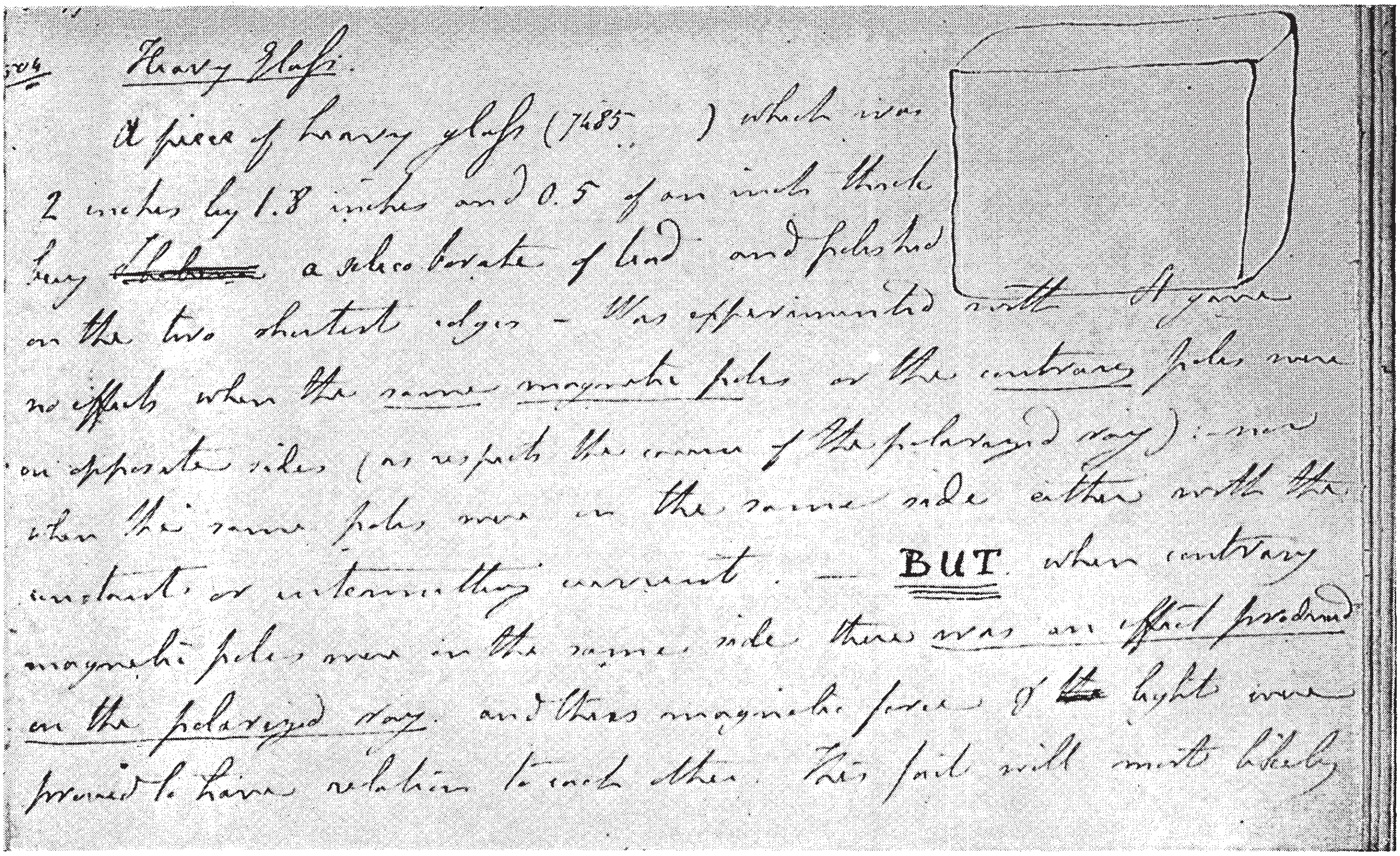

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Fig. 2. This page in Michael Faraday's diary for 13 September 1845 (reproduced here by courtesy of The Royal Institution) records the observation of the effect of a magnetic field on linearly polarized light passing through a piece of lead glass. A capitalized BUT was in order as this was the first experiment connecting light and magnetism.

had obtained a new and more powerful magnet and it made possible a second tremendous discovery, diamagnetism (his word), before his report on the first. On 4 November 1845 he found that his piece of heavy glass was repelled when placed in a strong nonuniform magnetic field.[20] This effect had actually been observed earlier for bismuth by Brugmans and by la Baillif, but it was Faraday who identified and explored the field in a systematic fashion. By filling soap bubbles with gases, he investigated their magnetic properties and found that oxygen was paramagnetic.[21] He thus carried out two monumental studies in a period of only three months.

Faraday's last published paper was a note on regelation.[22] His experiments on electrical discharges through gases at low pressures, with J. P. Gassiot[23], detailed in his diary, were never published. The term "Faraday dark space" is, however, a tribute to them and to earlier work in 1838.

Special mention should also be made here of Faraday's last laboratory effort, recorded in his diary on 12 March 1862. Here he details his unsuccessful efforts to observe an effect upon light sent through a magnetic field and then observed by use of a spectroscope. Again inadequate experimental equipment negated a brilliant concept, and the discovery was left for Zeeman in 1897. Certainly by Browning's standard that "A man's reach should exceed his grasp", Faraday was a very great man.

For readers concerned with motion pictures, brief mention may also be made here of Faraday's 1831 observation of the stroboscopic effect (also found by Plateau three years earlier) on which his invention of the "phenakistoscope", a toy with which James Clerk Maxwell played as a boy, is based.

In bringing this survey of his work to a close, at least bare mention is deserved for much other work such as: on sounds of flames in tubes[24], on the flow of gases through small bore tubes[25], on the flowing of sand under pressure[26], on acoustical figures for vibrating surfaces[27], on optical illusions[28], "on holding the breath for a lengthened period"[29], on the use of gutta percha for insulation[30], and on the transmission of light by thin sheets of gold and other metals, and by colloidal suspensions of these.[31]

Michael Faraday was born at Newington Butts, Surrey, near London, on 22 September 1791 (the year that Benjamin Franklin died), into the family of a smith of undistinguished Scottish, Irish and English ancestry. Times were hard, for England was involved in the Napoleonic war, and although the father was willing, he was often unable to work because of illness (he died in 1810), so sometimes even food for the family was scarce. Michael's parents were devout members of the Sande-

manian sect*, to whom poverty was acceptable. The family, including two older brothers and a younger sister, moved into London when he was five.

Quite understandably, the young boy received little education, and he later wrote, "My education was of the most ordinary description, consisting of little more than the rudiments of reading, writing and arithmetic at a common day school. My hours out of school were passed at home and in the streets". This limited education was to have later repercussions in that it accounts for some of the obscurity which other scientists found in his papers. When he was thirteen he became a newspaper delivery boy (and for such he always had a warm spot in his heart) for G. Riebau, a bookdealer. The following year he became an apprentice at bookbinding.

While learning this trade his interest in science was first aroused by reading *Conversations on Chemistry*, by Mrs. Jane Haldimand Marcet (the wife of Alexander Marcet, an able Swiss physician and chemist who had moved to London). From *Encyclopedia Britannica* articles he learned some electricity. Whenever he had the opportunity he attended scientific lectures, and in the spring of 1812 a customer, Mr. Dance, took him to hear four lectures by Sir Humphry Davy. Young Faraday made careful notes, recopied them, bound them, and sent them to Davy with a plea for his help in getting work in science. This led to his appointment in March 1813, at the age of 21, as a laboratory assistant to Davy at the Royal Institution, at 25 shillings a week.

The timing of the appointment was fortunate, for the following October Davy and his wife started on an extended European tour—despite the existence of a state of war between England and France at the time—and Faraday was taken along as an assistant and factotum. Their stay lasted until April 1815—about a month before the battle of Waterloo—and Faraday got to visit France, Belgium, Italy, and Switzerland, and, more importantly, to meet many eminent European scientists. Among these was Charles Gaspard de la Rive (1770–1834—whose son, Auguste, 1801–1873, was Faraday's close friend), "the first who personally at Geneva, and afterwards by correspondence, encouraged and by that sustained me".

After his return to London Faraday devoted himself chiefly to chemical investigations, to the development of laboratory techniques, and to giving himself the education he needed to supplement what he had learned in Europe and from Davy. He seemed to feel that he had to repeat any experiment himself before he could accept it completely. His first paper, on a chemical topic, appeared in 1816, and in May 1821 he was made Superintendent of the House and Laboratory.

The next ten years were devoted chiefly to problems in applied chemistry and, for a while, to considerable chemical consulting (which brought him about a thousand pounds in 1830). About 1829, however, he began to devote an increasingly larger portion of his time and effort to work of a more fundamental nature, and his consulting income dropped to 155 pounds in 1832. It has been estimated from his records that during the remainder of his life he could have earned a fortune of about 150,000 pounds had he not turned from applied to pure science.

With the passage of time his reputation grew, and recognition began to come to him. He became a corresponding member of the Academy of Sciences at Paris in 1823 (and a foreign associate in 1844), and that same year was elected to membership in the Royal Society (despite the active opposition of Davy, then its President, due to an unfortunate misunderstanding). In 1832 Oxford conferred the D.C.L. degree on him (at the same time as on Brewster, Brown, and Dalton). He received the Copley Medal of the Royal Society in 1832 and again in 1838*, and its Royal Medal and the Rumford Medal in 1845. Honorary memberships in scientific societies came to him from every country. No other honors were acceptable to him, neither election to important offices nor a title.

On 7 February 1825 he became Director of the Laboratory at the Royal Institution and began (on 3 February 1825) the custom of inviting its members to Friday evening lecture demonstrations. At that time he was being paid 100 pounds a year and assigned the quarters at the Institution which had housed Young and Davy in turn. In 1833 he was selected as the first Fullerian Professor of Chemistry, at 200 pounds a year, with no lecture obligations and life tenure (as a result of the grant from John Fuller). During the greater part of the twenty-six years he was at the Institution he received relatively little from it, while keeping it alive and flourishing by his lectures. From 1835 onward he was also a consultant for Trinity House relative to lighthouses.[32]

On 12 June 1821, when he was 30, he married the 21-year-old daughter of a silversmith—"an event which, more than any other, contributed to his earthly happiness and healthful state of mind" for forty-six years. It was his wish, however, that there should be "no bustle, no noise, no hurry occasioned even in one day's proceedings" and that the day be "just like any other day"—and so it was, although some of his relations were offended by not being invited to the wedding. About a month later he followed the family tradition and joined the Sandemanian church. In 1850 he became an elder and took his turn regularly on alternate Sundays in preaching and conducting services, for three and a half years.

As early as 1831 Faraday began to have trouble remembering things, and in a July 1836 letter wrote, "my memory is indeed a very bad one now". Also

* This sect was founded by John Glas in Scotland, and separated from the Presbyterian church about 1725; Glas was succeeded by his son-in-law, John Sandeman, who died in Connecticut in 1771 after living there seven years.

* He was the third man to be so honored twice; Stephen Grey received it in 1731 and 1732, and Canton in 1751 and 1764; Desaguliers received it in 1734, 1736, and 1741.

beginning about 1839 he was apparently plagued by almost constant and severe headaches, and became more and more dependent upon the copious notes in his diary. In November 1840 he wrote of having suffered a headache for four months. His condition became progressively worse, and finally he was forced to stop work completely. A summer vacation in Switzerland in 1841 helped, but he continued to suffer from fits of giddiness and failing memory, and could not resume his work. In 1843 he wrote that he was "one who feels as if his purpose in life in this world were passed...My health and spirits are good, but my memory is gone...I, though I may gain from day to day some little maturity of thought, feel the decay of powers, and am constrained to a continual process of lessening my intentions and contracting my pursuits". By 1844, he did get back to his laboratory again (though he withdrew completely from social activities) to work for another ten years. He regained his physical health more or less completely, but he was still plagued by a completely unreliable memory. This seriously restricted the scope of his researches and largely prevented any use of the literature, but at the same time made his studies personal and entirely independent.

In 1858 Prince Albert influenced Queen Victoria (28 years Faraday's junior) to provide a house for him on the Green at Hampton Court, for his condition was becoming desperate. The deterioration of his memory and his reasoning ability came in irregular steps, and in a letter dated 1 August 1864 he wrote "...although I am not able to remember at the end of a line what was said at the beginning of it..." There were only moments of lucidity when the general confusion disappeared, so he discontinued his studies and spent his last years peacefully, under the care of a niece. Despite his progressively worse mental situation, he remained in generally good health, and his death came peacefully on 25 August 1867, while seated in a chair at his desk at home.

The Royal Society *Catalogue of Scientific Papers* lists 158 papers for him, and many of these were reprinted. His first appeared in 1816 and his last in 1860, and experimental findings were presented in essentially all of them. Nine of the Ostwald *Klassiker* volumes are devoted to translations of his papers. Experiment was for Faraday not so much a tool for discovery as a method for critical examination of his ideas. As he put it, "Without experiment, I am nothing.... All our theories are fixed upon uncertain data, and all of them want alteration or support from facts". He was blessed in his work with the gift for noticing both the anticipated and the unexpected.

Not only did Faraday generate knowledge, he diffused it. He was a brilliant lecturer and did much to bring science to the people, old and young. While much of his fame came from the "Friday evening discourses" for adults (he once gave one—1 March 1833?—in place of Wheatstone, who became overwhelmed with stage fright just before he was supposed to talk), he also took an active part in the "Christmas Lectures" which are still a feature for young people at the Royal

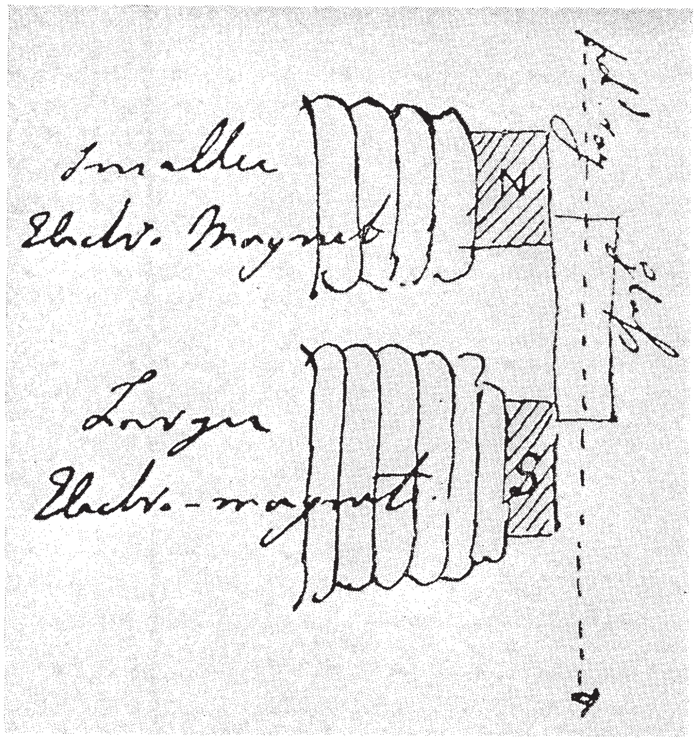


Fig. 3. Reproduction of Faraday's sketch in his laboratory notebook for 13 September 1845, showing the ends of the "Smaller Electromagnet" and the "Larger Electro-magnet", with the "pd' ray" passing through the "glass". From *Faraday's Diary* (G. Bell and Sons, Ltd., London, 1933) Vol. IV, p. 264.

Institution.[33] Possibly his own experiences as a youth led Faraday to give so much attention to these demonstration lectures. His flair for lecturing was notable and his presentations charmed all, old and young, naive and sophisticated.[34] (He once made a cage 6 ft in diameter and performed experiments in it while suspended in mid-air.)

Faraday paid much attention to the matter of nomenclature. In a letter to Whewell dated 21 February 1831, he wrote "I cannot help thinking it a most unfortunate thing that men who as experimentalists and philosophers are the most fitted to advance the general course of science and knowledge, should by the promulgation of their own theoretical views under the form of nomenclature, notation or scale, actually retard its progress. It would not be of much consequence if it was only theory and hypothesis which they thus treated, but they put facts or the current vein of science into the same limited circulation when they describe them in such a way that the initiated only can read them." He also wrote, relative to electrolysis, "These terms being once well defined, will , I hope, in their use enable me to avoid much periphrasis and ambiguity of expression. I do not mean to press them into service more frequently than will be required, for I am fully aware that names are one thing and science another."

Apparently Faraday was quite prepossessing in appearance. He was a relatively small man, but well-built and active. He was chiefly characterized by quickness—in movement, thought, feeling, and perception—and by vividness of expression. All who knew

him spoke of the "brightness" of his manner and his vivacity. He had an unusually animated face, a pleasant laugh, and an ingratiating frankness. He seems to have been unusual physically only in that the length of his head from front to back was so great that he had to have his hats custom made. He had a real love for literature, as his gift for writing proclaims. He had no particular hobby or recreation, but joined happily in the activities of others. He loved the theater, travel, children, boating, camping up the river, and the zoological gardens. He was a great walker and thought nothing of a 30-mile walk, and even at the age of 54 once walked 45 miles in a day. He was unusually sensitive to odors, almost abnormally so: he disliked the odor of tobacco, abhorred musk, could not tolerate the fumes from extinguished candles and oil lamps, and was quite fond of eau de Cologne.

He was generous and charitable: money did not appeal to him in the slightest except as a means to provide moderate comfort. His world was the laboratory and the lecture rooms, and he had a remarkably complete lack of interest in or awareness of the world of affairs—politics, the great events, and the international crises of his time, went unnoticed.

Lord Kelvin had this to say of him: "I wish I could put in words something of the image which the name of Faraday always suggests to my mind. Kindliness and unselfishness of disposition; clearness and singleness of purpose; brevity, simplicity, and directness: sympathy with his audience or his friend; perfect natural tact and good taste; thorough cultivation—all these he had to a rare degree; and their influence pervaded his language and manner, whether in conversation or lecture. But all these combined made only a part of Faraday's charm. He had an indescribable quality of quickness and life. Something of the light of his genius irradiated his presence with a certain bright intelligence, and gave a singular charm to his manner which was felt by everyone, surely, from the deepest philosopher to the simplest child who ever had the pleasure of seeing him in his home—the Royal Institution."

Among the great number of sources of information on Faraday[35] is the first of the "Scientific Worthies" series[36] which was inaugurated in *Nature* in 1873 with a tribute to him and a portrait of him. The steel engraving was by Jeans from a photograph by Watkins. In this tribute[37] (presumably by Norman Lockyer) appear the following words: "It is to be hoped that the nobleness of his simple, undramatic life, will live as long in men's memories as the discoveries which have immortalized his name. Here was no hunger after popular applause, no jealousy of other men's work, no swerving from the well-loved, self-imposed task of 'working, finishing, publishing'."

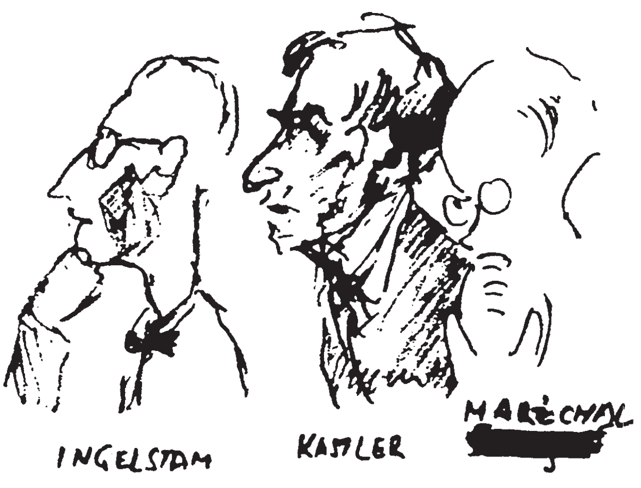
His close friend and successor at the Royal Institution, John Tyndall, deserves the last word. "Taking him for all and all, I think it will be conceded that Michael Faraday was the greatest experimental philosopher the world has ever seen; and I will add the opinion, that the progress of future research will tend, not to dim or to diminish, but enhance and glorify the labours of this mighty investigator."

References

1. Phil. Trans. Roy. Soc. London **136**, 1 (1846), or *Experimental Researches in Electricity*, Vol. 3, p. 1, recently reprinted by Dover Publications, Inc., New York. Found also in Phil. Mag. [3], **28**, 64 and 294 (1846) and **29**, 153 and 249 (1846) and Am. J. Sci. [2], **1**, 425 (1846). An excerpt appears on p. 352 of *A Source Book in Physics*, by W. F. Magie (McGraw-Hill Book Company, Inc., New York, 1935 and recently reissued by Harvard University Press).
2. Phil. Mag. [3], **8**, 521 (1826).
3. Quart. J. Sci. **12**, 74 and 283 (1822).
4. Phil. Trans. Roy. Soc. London **113**, 160 and 189 (1823), and Quart. J. Sci. **16**, 229 (1824). (These are reprinted in the Alembic Club Reprint No. 12, *The Liquefaction of Gases*, Edinburgh, 1935.) Others had liquefied gases earlier, e.g., Northmore condensed chlorine in 1805. See Phil. Mag. [3] **8**, 521 (1836) and **26**, 253 and 450 (1845); Phil. Trans. Roy. Soc. London **135**, 155 (1845); Nature **17**, 177 (1878); and Proc. Roy. Soc. (London) **5**, 547 (1845).
5. With J. Stodart, Phil. Mag. **56**, 26 (1820); Phil. Trans. Roy. Soc. London **112**, 253 (1822).
6. Phil. Trans. Roy. Soc. London **120**, 1 (1830). This was his first Baker lecture. This lectureship was endowed in 1774 by Henry Baker and provided that four pounds be paid for an annual lecture before the Royal Society.
7. Phil. Trans. Roy. Soc. London **122**, 125 (1832). Excerpts from this great paper are to be found in Magie (Ref. 1), p. 473, and in *Great Experiments in Physics*, by M. H. Shamos (Henry Holt and Company, New York, 1959), p. 131. Brief announcements of his discovery also appeared in Phil. Mag. [2] **11**, 300 and 462 (1832) and [3] **1**, 61 (1832); and in Am. J. Sci. **22**, 386 and 409 (1832).
8. "Around the magnet, Faraday
Is sure that Volta's lightnings play;
But *how* to draw them from the wire?
He took a lesson from the heart:
'Tis when we meet, 'tis when we part,
Breaks forth the electric fire."
Blackwood's Magazine **61**, 367 (March, 1847).
9. The various "series" were distributed over the years as follows: 1832—1, 2; 1833—3, 4, 5; 1834—6, 7, 8; 1835—9, 10; 1836—none; 1837—none; 1838—11, 12, 13, 14; 1839—15; 1840—16, 17; 1841—none; 1842—none; 1843—18; 1844—none; 1845—none; 1846—19, 20, 21; 1847—none; 1848—none; 1849—22; 1850—23; 1851—24, 25, 26, 27; 1852—28, 29; 1853—none; 1854—none; 1855—none; 1856—30. The 30 series incorporate studies numbered through 40, with 34 and 37 apparently omitted. Much of this material was reprinted in various journals, particularly in the Philosophical Magazine, either completely or in abridged form.
10. Reviewed by Tyndall in Phil. Mag. [4], **11**, 404 (1856). Selections are also available in the Everyman's Library volume No. 576.
11. Henry—Am. J. Sci. **22**, 408 (1832); Faraday—Phil. Trans. Roy. Soc. London **125**, 41 (1835). See also Magie (Ref. 1), pp. 513 and 485.
12. Phil. Trans. Roy. Soc. London **123**, 675 (1833).
13. Phil. Trans. Roy. Soc. London **124**, 77 (1834) and Phil. Mag. [3] **5**, 161, 252, 334, and 424 (1834). Excerpts from this are to be found in Magie (Ref. 1) and Shamos (Ref. 7), p. 146.
14. See "Faraday consults the scholars: the origins of the terms of electrochemistry", S. Ross, Notes Rec. Roy. Soc. London

16, 187 (1961). Faraday was helped in this connection by Whitlock Nicholl (1746–1838) and William Whewell (1794–1866). It was Whewell who in 1840 also originated the words "scientist" and "physicist". Faraday liked the first and strongly disliked the second, preferring to be known as a "philosopher".
15. Phil. Trans. Roy. Soc. London **123,** 23 (1833); Phil. Mag. [3] **3,** 161, 253, and 353 (1833).
16. Phil. Trans. Roy. Soc. London **128,** 1, 79, 83, and 125 (1838); Phil. Mag. [3] **13,** 281, 355, and 412 (1848) and **14,** 34 (1839). For an excerpt see Magie (Ref. 1), pp. 498 and 501.
17. Phil. Mag. [3] **22,** 200 (1843); excerpts from this are to be found in Magie (Ref. 1), p. 489 and Shamos (Ref. 8), p. 142.
18. Proc. Roy. Inst. **1,** 216 (1851–1854)—from which Magie (Ref. 1) excerpts, p. 506; Phil. Mag. [4] **3,** 401 (1852). See also Proc. Cambr. Phil. Soc. **1,** 163 (1843–1863) and Phil. Mag. [4] **11,** 404 and **12,** 316 (1856) for papers by Clerk Maxwell. This facet of Faraday's work is treated in detail by L. Pearce Williams in his recent full-length biographical study.
19. *Faraday's Diary* (G. Bell and Sons, Ltd., London, 1933), para. 7503.
20. Phil. Trans. Roy. Soc. London **136,** 21 and 41 (1846); Phil. Mag. [3] **28,** 147, 396, and 455 (1846) and **29,** 153, 156, and 249 (1846); Am. J. Sci. [2] **1,** 421 (1846).
21. Phil. Trans. Roy. Soc. London **136,** 52 (1846); Phil. Mag. [3] **31,** 401 (1847) and **37,** 545 (1850); Am. J. Sci. [2] **2,** 233 (1846).
22. Proc. Roy. Soc. London **10,** 440 (1859–1860); Phil. Mag. [4] **17,** 162 (1859); J. Franklin Inst. **39,** 270 (1860); and Am. J. Sci. [2] **31,** 414 (1861).
23. See the paper by J. P. Gassiot, Phil. Trans. Roy. Soc. London **148,** 1 (1858). Faraday introduced the term "radiant matter" which Crookes adopted.
24. Quart. J. Sci. **5,** 274 (1818).
25. Quart. J. Sci. **3,** 354 (1817) and **7,** 106 (1819).
26. Phil. Mag. [2] **8,** 68 (1830).
27. Phil. Trans. Roy. Soc. London **121,** 229 (1831).
28. J. Roy. Inst. **1,** 205 (1831).
29. Phil. Mag. [3] **3,** 241 (1833).
30. Phil. Mag. [3] **32,** 165 (1848).
31. Phil. Mag. [4] **14,** 401 and 512 (1857).
32. Phil. Mag. [4] **19,** 320 (1860).
33. The first "Christmas Course of Lectures Adapted to a Juvenile Auditory" was given by J. Wallis, beginning 29 December 1826. Each course consists of six lectures, starting at 3 p.m., on the first Tuesday, Thursday, or Saturday after 26 December and continuing on those days. Being primarily for young people, the first six rows of seats are reserved for them, and adults sit elsewhere. Faraday gave the second series in 1827, and gave his last just before his retirement, six years before his death. Faraday gave 19 sets, Tyndall 12, James Dewar 9, and W. Bragg 4. Many of these lecture series have led to books such as Faraday's *The Chemical History of a Candle* (1860 series) and *On the Various Forces of Nature* (1859 series), and the splendid books by Bragg.
34. His comments and suggestions for lecturers should be required reading for all lecturers on scientific topics. Some of his comments are readily available in the ten pages of *Michael Faraday—Advice to a Lecturer*, edited by Geoffrey Parr, and published by the Royal Institution, London, 1960. They are as pertinent now as when he wrote them at the age of 21.
35. I should like to recommend particularly the following: W. Crookes, preface to *On the Various Forces of Nature*; J. Clerk Maxwell's sketches in the *Encyclopedia Britannica* (8th and 11th editions); W. Garnett, *Heroes of Science—Physicists* (London, 1885); H. von Helmholtz, J. Chem. Soc. **39,** 277 (1881); Bence Jones, Proc. Roy. Soc. (London) **17,** i (1868–1869) and *The Life and Letters of Faraday*, 2 vols., 2nd ed. (Longmans, Green and Co., London, 1870); H. Kondo, Scientific American **189,** 90 (October, 1953); P. F. Mottelay, *Bibliographical History of Electricity and Magnetism* (Charles Griffin and Co., London, 1922), p. 483; W. L. Randall, *Michael Faraday* (1791–1867), (Leonard Parsons, London, 1924); W. F. G. Swann, Science **74,** 433 and 462 (1931); S. P. Thompson, *Michael Faraday, His Life and Work* (London, 1901); J. Tyndall, *Faraday as a Discoverer* (London, 1868, 1870) and his sketch in the *Dictionary of National Biography*; and L. P. Williams, *Michael Faraday* (Basic Books, Inc., New York, 1965) and his paper in The Physics Teacher **3,** 64 (1965).
36. Isis **56,** 354 (1965).
37. Nature **8,** 397 (1873).

Another ICO-7 Sketch



See also pages 602, 630, 673, 718 and 778